VALIDATION OF MODIS-DERIVED TOP-OF-THE-ATMOSPHERE SPECTRAL RADIANCES BY MEANS OF VICARIOUS CALIBRATION

Submitted to the EOS Validation Office by

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Version 1.3

November 1996

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1.0 Introduction

This validation plan applies to the Vicarious Calibration (VC) of the Top of the Atmosphere (TOA) radiance, i. e. the Level-1B data product or at-sensor radiance, as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS). These are data that will have been radiometrically corrected but will not have been geometrically corrected or re-sampled.

This validation plan does not cover the details of the Level-1B algorithm and its ATBD; rather it is the plan for validating the testing of the Level-1B algorithm data product. Although the requirements for VC validation are in many ways unique, this plan adheres closely to the outline recommended by the EOS Validation Office for general algorithm validation.

VC is the use of calibrated sources external to MODIS in order to validate the On-Board Calibrator (OBC) derived radiances (Slater et al, 1996). For a selected site, the radiance or reflectance is measured either on the ground or from an aircraft. Also needed are measurements of atmosphere characteristics and a Radiative Transfer Code (RTC) to determine the TOA radiance. VC-derived TOA radiance, when compared to the MODIS-determined radiance, constitutes the validation of the MODIS Level-1B data product.

Other sources that are external to MODIS which will be used in the validation of the Level-1B data product are the moon (Keiffer and Wildey, 1996) and selected sites that have been measured by other satellite-borne sensors, i. e. cross calibrations with EOS and non-EOS sensors.

This plan represents the validation activities to be pursued by the Remote Sensing Group (RSG). For several years, particularly since the meeting in August 1995 to brief the MODIS Characterization Support Team (MCST) on VC, we have continued to exchange ideas with MCST on how VC results should be used for calibration validation. We expect this close collaboration will continue for the duration of the MODIS in-flight program.

1.1 Measurement and science objectives

The measurement objective of this validation activity is to determine the TOA radiance of a selected site by means which are accurate and independent of the MODIS-determined radiance. The science objective is to verify the accuracy of the MODIS-determined TOA radiance which is the basis for many other science data products.

1.2 Missions

A MODIS instrument will be included on the EOS AM-1 platform, to be launched in mid-1998, and the EOS PM-1 platform launched approximately two years later. MODIS instruments are planned for the second AM and PM platforms to be launched in 2004 and 2006, respectively. Vicarious calibrations will be used to validate the accuracy of the TOA radiance as measured by both the AM and PM instruments and to facilitate cross-calibration checks between these two MODIS instruments as well as with other EOS and non-EOS sensors.

1.3 Product description

The data product is the difference between MODIS-derived TOA radiance, for a selected site and in a specific MODIS band, and that predicted by the VC for the same site. These measured differences will be used to validate the MODIS Level-1B algorithm and by inference the OBCs. In those instances where the difference in the VC-predicted and MODIS-determined TOA radiances are larger than the combined uncertainty of the two techniques, the data product will be used to correct the radiometric calibration coefficients.

2.0 Validation Criteria

2.1 Overall approach

The overall validation procedure is diagrammed in Figure 1. The TOA radiance from a VC site is measured by MODIS, i. e. converted to digital counts (DCs). Then, using the most recent set of calibration coefficients, TOA radiances are produced by the Level-1B algorithm using the DCs obtained from Level-1A processing. The calibration coefficients and appropriate corrections are developed in the MODIS Level-1B algorithm which uses the data from the OBCs as input (Guenther et al, 1995). The Level-1B algorithm will also include procedures to correct for some of the changes in the characteristics of the OBCs themselves. The Level-1B algorithm is being developed by the MCST. It will also be implemented by MCST.

The MODIS-derived and VC-predicted radiances are compared. If the differences exceed their combined uncertainty then the calibration coefficients need to be adjusted. Issues such as the timing and threshold of a change in calibration coefficients and the weights to be applied to each set of measurements will be settled by a calibration advisory panel convened to assist the MODIS Characterization Support Team (MCST) in reaching a decision.

In the VNIR (visible and near infrared) and SWIR (short wave infrared) the VC-determined TOA radiance is obtained in one of two ways: either by measurement of the spectral reflectance of the site which in the RTC calculation is multiplied by the atmosphere-corrected solar spectral irradiance to obtain radiance; or by direct measurement of the site's spectral radiance. The measurements can be performed either on the ground or from an aircraft. In both cases the on-ground or low-altitude radiance is corrected for scattering and absorption due to the atmosphere.

In the TIR (thermal infrared, i. e. mid-wave to long wave infrared) the VC-determined TOA radiance is obtained by measuring the radiance on the ground or at a low altitude and then applying the corrections for the atmospheric effects.

For high accuracy in a VC radiance measurement, one requires an accurate absolute calibration of the VC instrumentation and a thorough knowledge of their radiometric characteristics. It is important to select the calibration site and measurement conditions so that several criteria are met. One needs the highest obtainable, but not saturated, signal levels in the MODIS bands. The site area should be flat and larger than several IFOVs (instantaneous field of view) of a MODIS pixel. The site should be uniform in reflectance over this area and its reflectance should be spectrally flat. Finally, the relative magnitude (compared to the radiance) of the corrections for atmospheric effects should be small so that the RTC can accurately predict the radiance at the TOA.

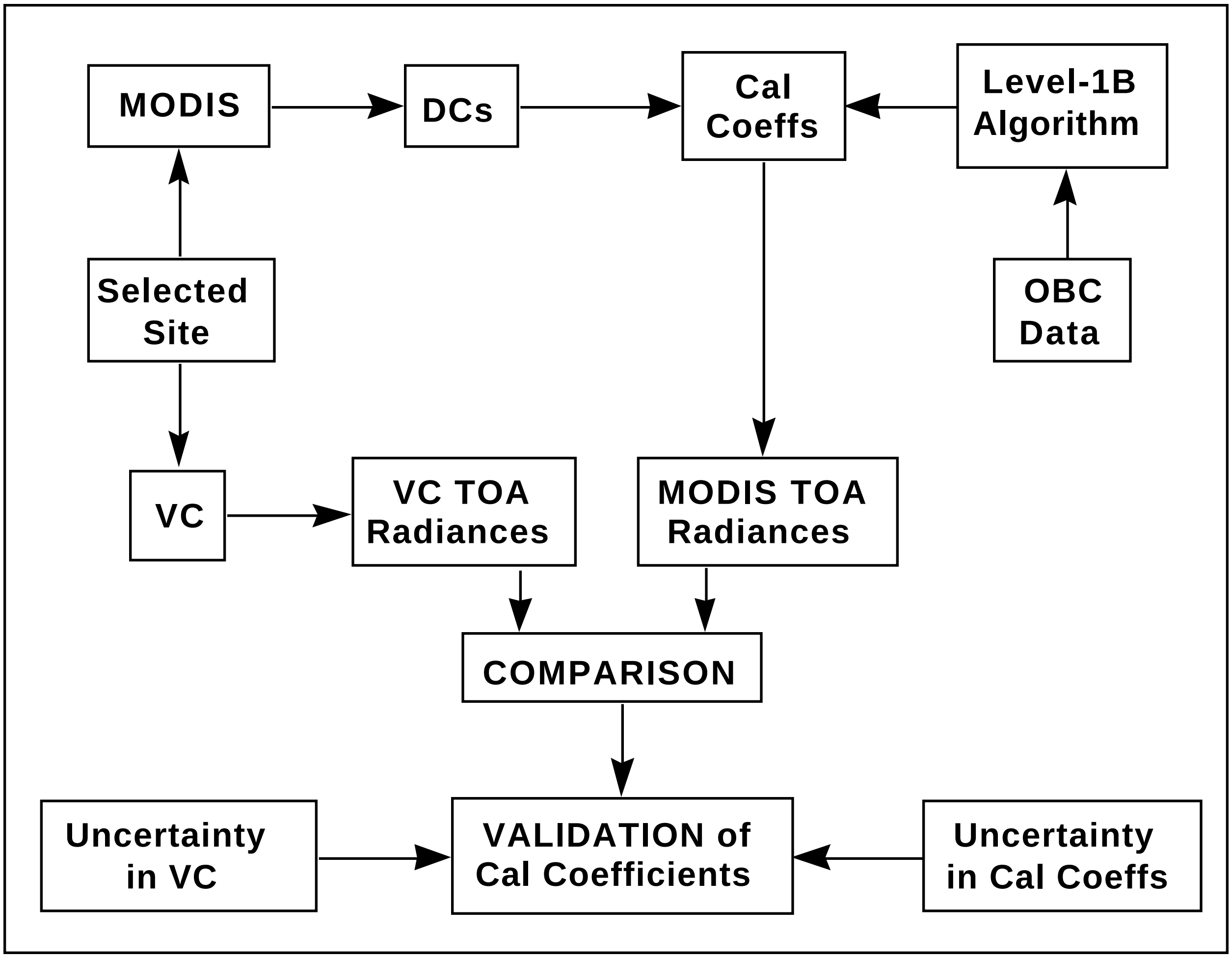

Figure 1. Validation process for MODIS calibration coefficients.

Although it does not directly affect the accuracy of a VC measurement, an important practical consideration is the location of the site. It must be readily accessible by the members of the VC team along with their equipment.

There is no ideal calibration site that satisfies all of the above conditions. Furthermore, no one site can satisfy the requirements of all the MODIS bands simultaneously. Obviously trade-offs among different sites will have to be made.

In the Southwestern United States there exist several fairly uniform reflectance sites which have been used over the course of many years by the RSG for calibrations of Landsat-TM, SPOT-HRV, and other airborne and satellite-borne imaging sensors. For the 0.25 x 0.25 km and 0.5 x 0.5 km IFOV bands of MODIS, VCs can be performed at Ivanpah Playa and Lunar Lake Nevada, and White Sands New Mexico. Ivanpah Playa and Lunar Lake have reasonable reflectance levels and small spectral variations in the VNIR and SWIR. These are desert sites where the aerosol loading of the atmosphere is typically low with correspondingly reduced corrections. In the VNIR, the White Sands site has a fairly flat spectral reflectance which is quite high, however, the reflectance is much lower and spectrally structured in the SWIR. Railroad Valley in Nevada is a much larger, reasonably uniform reflectance site whose spectrum is fairly flat over most of the VNIR and SWIR. All the sites, with the exception of Ivanpah Playa, are above 1.3 km so that atmospheric corrections are typically small.

The radiance from the land sites discussed above will be generally high which means that the MODIS ocean color bands would be saturated. For the ocean color bands Lake Tahoe which is at a high altitude in Northern Nevada/California will be used as the VC site. The Lake Tahoe site also will be used for VC measurements in the TIR. The VC measurements at Lake Tahoe will employ the radiance-based approach and will be made from an aircraft. A large body of water is selected for the TIR VC site because of its uniformity and stability due to its large thermal mass and high thermal conductivity of water.

In regard to the VC of the MODIS ocean color bands at the Lake Tahoe site, it should be noted that because of the low aerosol loading and the resulting reduced atmospheric scatter, the overall TOA radiance is reduced compared to lower altitude sites. Added to this is the fact that in the long wave ocean color band the upwelling radiance of the water is also very low. The result is then that the effect of sun glint with respect to the overall radiance is quite significant, particularly at the long wave band. Since sun glint is proportional to wind velocity and has a high degree of angular dependence, the accuracy of the VC will be dependent upon the wind conditions at the lake surface and the pointing accuracy of the airborne radiometer.

2.2 Sampling requirements and trade-offs

VC measurements will be made at the same time as an overpass of MODIS. As noted above, in the VNIR and SWIR two types of VC methods are possible: reflectance-based and radiance-based. Reflectance measurements are made on the ground by transporting a downward looking spectroradiometer over the site either by walking the site or by using a motorized vehicle for more rapid coverage of the site. The spectroradiometer is calibrated in reflectance units by periodically viewing a solar irradiated target of known reflectance. Sampling is done at many regularly spaced intervals in a predetermined pattern over the site. The spacing of the samples depends of course upon the non-uniformity of the site. For the 1 km and 0.5 km IFOVs of MODIS, carrying the spectroradiometer is unfeasible because the time required increases uncertainties due to changing atmospheric conditions and surface reflectivity effects.

For radiance-based VC measurements, an absolutely calibrated spectroradiometer is used to measure the spectral radiance of the site directly. The spectroradiometer is calibrated in the laboratory by viewing a calibrated radiance source. Two methods are possible, either the source is a panel of known diffuse reflectance illuminated by a calibrated incandescent lamp, or it's an integrating sphere internally illuminated with incandescent lamps. In either method the calibration is traceable to a NIST-calibrated spectral irradiance lamp standard.

In both radiance-based and reflectance-based measurements, the spectroradiometer may be mounted in an aircraft and flown in a raster pattern over the site. By using an aircraft, the time required to obtain a complete set of measurements is of course greatly reduced. Another advantage of airborne measurements is that the aircraft can be above most of the atmospheric effects. The atmospheric corrections are therefore smaller and relatively more accurate. Also, by using an aircraft it is possible to obtain measurements at several altitudes a vertical profile of the atmospheric constituents can be obtained. This additional information will assist in the verification of the RTC calculation of TOA radiance.

Because of the complexity of a multi-band instrument which would include all the MODIS VNIR and SWIR bands, a trade-off will be made in the number and spectral location of the bands in the VC radiometer. The multi-band VC radiometer will be built for optimum stability and calibrated to the highest accuracy possible. Using a spectrometer that is less stable (and consequently less accurate), narrow-band (about I nm) spectral information will be obtained for the site. These relative measurements will be used to interpolate the more accurate VC radiometer data. The interpolated reflectance (or radiance) data along with the spectrally detailed atmospheric characterization by the RTC will be used to predict the TOA radiance at 1 nm intervals.

For the TIR, a radiance-based VC will be used since there is nearly zero reflected radiation. We are not considering using an emissivity-based approach. For the radiance measurement a multi-band radiometer will be calibrated by reference to a blackbody simulator source which is traceable to a NIST temperature standard. The RSS of the uncertainty of the temperature standard, the uncertainties in the corrections to Planckian behavior, and the instability of the TIR radiometer is the uncertainty in the absolute accuracy of the radiance calibration. Adequate stability of a TIR radiometer in an aircraft has yet to be demonstrated.

At this point in time it appears that the achievable accuracy of an airborne TIR radiance measurement will be insufficient to validate the most stringent accuracy requirements for MODIS in the TIR. Until improved TIR radiometer stability and accuracy have been adequately demonstrated, the detection of only the larger errors in the MODIS-derived TIR radiance appears possible.

As in the VNIR and SWIR a multi-band instrument which would include all the MODIS TIR bands will be very complex so that a trade-off is being made in the number and spectral location of the bands in the VC radiometer. In the TIR the bands which have the most stringent accuracy requirement are bands 31 and 32. These are the SST (Sea Surface Temperature) bands at approximately 11 and 12 mm. Since only bands 31 and 32 will be validated directly, the others will be checked by reference to these bands via their relationship to the on-board blackbody.

An additional consideration in the trade-off is the effect of the atmosphere, specifically the absorption and thermal radiative emission of water vapor. Bands 31 and 32 are located in a spectral region where the absorption coefficient and hence the radiance of the water in the atmosphere is at a minimum and the atmospheric transmittance is at a maximum. Therefore the relative accuracy of the atmospheric corrections is optimum at these two bands.

It is planned that the TIR VC measurements will be made using Lake Tahoe as the selected site with the radiometer aboard an aircraft. A raster scan of the radiance will be made to determine the thermal uniformity of the lake surface. This will be done at several altitudes to determine the vertical profile of the atmospheric effects. Balloon radiosonde data will also be used in the determination of the vertical profile of the temperature and water content of the atmosphere. As in the VNIR and SWIR, the measured radiances will be extrapolated using an RTC calculation to obtain TOA radiance at the time of the sensor overpass.

In summary, the trade-offs being made are to: (1) use a radiance-based approach aboard an aircraft for the VC in the VNIR, SWIR and TIR; (2) on-ground reflectance based VCs will be performed and in some cases will serve to cross-check the airborne radiance VCs; (3) in those cases where aircraft data are not available a reflectance-based VC will be used in the validation of the Level-1B VNIR and SWIR data products; (4) not all MODIS VNIR and SWIR bands will be measured by the radiometer, detailed spectral reflectance and atmospheric characterization information will be used for interpolation; (5) in the TIR only two of the sixteen bands will be measured; and (6) several different sites will be used to perform VCs.

2.3 Measures of success

Success of a VC is measured in terms of the accuracy attained in the determination of the TOA radiance. Success of the validation of the Level-1B data product is determined by the consistency of agreement, or disagreement, between the MODIS-measured and VC-predicted TOA radiances in successive VC campaigns. Consistency of agreement/disagreement between successive VC campaigns is judged within the combined limits of uncertainty of the two techniques for determining TOA radiance. It is expected that the MODIS-measured TOA radiance will have better precision than that of the VC-predicted TOA radiance. The precision of the set of VC measurements is limited by the large variability of the atmospheric conditions and surface reflectance over the long time span covered by the measurement set. The accuracy of the VC-determined TOA radiance will probably be better than that of the MODIS-determined radiance because systematic errors that occur after launch are not predictable and may not be detectable.

Assessment of accuracy of the VC measurements will come by several routes: validation of the accuracy of the laboratory standards; comparison of two different VC methods; peer review of procedures and uncertainty estimates; and, finally, field campaigns in which several different VC teams will compare their methods for predicting TOA radiance.

In the case of laboratory standards, calibration comparisons with other laboratories will be used where available to verify accuracy. The accuracy of the laboratory standard is a component of the total uncertainty estimates for the VC, and these uncertainty estimates will be subjected to peer review.

For the VNIR and SWIR the RSG has developed highly stable transfer radiometers whose absolute radiance calibrations are based on a NIST-calibrated spectral irradiance standard lamp. These radiometers have been used in intercomparisons of the absolute radiance standard sources used for calibrations by the manufacturers of MODIS, MISR, ASTER, Landsat-7, SeaWiFS and OCTS. These comparisons involve the standards and calibration instrumentation of each of the aforementioned sensors. Furthermore, in many of these intercomparisons NIST was represented. This means that the absolute spectral radiance calibrations within the RSG laboratory (and hence into the field) are traceable to NIST by more than one route; and the RSG calibrations are also traceable to the calibration bases of several EOS and non-EOS sensors. Some of these intercomparisons are ongoing at this time, hence final results are not available.

In the VNIR and SWIR, the results of measurements made using both radiance-based and reflectance-based techniques will be compared. Agreement within the combined predicted uncertainties will indicate that the measurements were successful. Previous comparisons of the two techniques indicated agreement to within 4% (Biggar et al, 1991). It is expected that the substantial improvements in instrumentation that have been made since the time of that comparison will show better agreement between the two techniques at this time.

Also in the VNIR and SWIR it is possible to compare a laboratory standard calibration and a Solar Radiation Based Calibration (SRBC) as separate bases for the radiance VC method. An initial comparison has been done and shown to be in agreement to within 3.5% (Biggar, 1996). It is expected that further refinements of these techniques will show improved agreement.

The estimated uncertainties are presented in Table 1 for a reflectance-based VC that includes diffuse-to-global solar irradiance measurements (Slater et al, 1996). The estimates labeled “Present” are for a good VC day at White sands, New Mexico: cloud-free with good visibility of 100 km or more. It is estimated that at present the total uncertainty is 3.5%. It is anticipated that

Source	Present		Anticipated	
	Uncer-tainty	**Total uncer-tainty**	**Uncer-tainty**	**Total uncer-tainty**
Extinction optical depth	5.0	1.0	5.0	1.0
Diffuse-to-global ratio measurement		2.3		1.7
Field measurement	2.0	0.5	2.0	0.5
Blocked diffuse component	2.0	0.5	2.0	0.5
Extrapolation to new angles	1.0	0.25	1.0	0.25
Panel BRF correction (θ_{sun} ~ 50°)	2.2	2.2	1.5	1.5
Ground reflectance measurement	2.1	2.1	1.2	1.2
Non-lambertian ground characteristic	1.2	1.2	1.2	1.2
Spherical albedo and atmospheric reflectance		1.0		1.0
Atmospheric model error	1.0		1.0	
Uncertainty in μ_{sun} and μ_{view}	0.4	0.1	0.4	0.1
Total uncertainty (root sum of squares)		3.5		2.8

Table 1. Estimated uncertainties for a reflectance-based VC measurement.

improvements will be made in the panel BRF and ground reflectance measurements so that the total uncertainty will be reduced to 2.8%.

In Table 2 the estimated uncertainties for a radiance-based VC are listed for the present status of the measurements and the anticipated improvements (Slater et al, 1996). Again the “Present” uncertainty estimates are for a good VC day at White sands, New Mexico. The present and anticipated uncertainties are 2.8% and 1.8%, respectively. As in the case of the reflectance-based VC, panel calibration accuracy is expected to improve. In addition, the uncertainties in the standard lamp, i. e. the lamp calibration and scale uncertainty, are also expected to decrease.

The combined uncertainties of the reflectance- and radiance-based techniques is 4.5%. This is within the measured level of agreement reported by Biggar et al (1991) thereby confirming the combined estimated total uncertainty. If the anticipated improvements are realized then the combined uncertainty will be 3.3%, where the reflectance technique contributes less than 3% and the radiance technique less than 2%. The present levels of uncertainty are sufficient to validate the accuracy of the VNIR and SWIR bands of MODIS.

Source	**Present**		**Anticipated**	
	Uncer-tainty	**Total uncer-tainty**	**Uncer-tainty**	**Total uncer-tainty**
Radiometer calibration		2.5		1.6
Panel calibration	2.0		1.0	
Lamp calibration	1.3		0.9	
Scale uncertainty	1.2		0.8	
Transfer uncertainty	0.5		0.5	
Lamp positioning	0.3		0.3	
Lamp current stability	0.5		0.5	
Voltage measurement uncertainty	0.5		0.5	
Measurement accuracy		1.3		0.9
Data logger accuracy	0.5		0.5	
Radiometer stability	0.5		0.5	
Pointing angle uncertainties	1.1		0.5	
Correction for altitude difference		<0.1		<0.1
Uncertainty in the reflectance-based method	5.0		3.0	
Total uncertainty (root sum of squares)		2.8		1.8

Table 2. Estimated uncertainties for a radiance-based VC measurement.

The TIR measurements using the airborne radiometer will be compared to temperature measured at the surface of the water. The predicted radiance of the water obtained from the measured temperature, corrected for the emissivity of water and the atmospheric effects will be compared to the radiance measured at the aircraft.

In addition to the above accuracy checks, the TOA radiance as predicted by several different VC calibration teams will be compared. The first of these cross-calibration campaigns took place in late May, early June of 1996. Participants included teams from MODIS, ASTER and MISR. The results from this cross-calibration campaign are being evaluated. Future cross-calibrations are planned. It is expected that these campaigns will occur annually and will have broader international participation.

The success of the extrapolation of the radiance to the TOA is the relative accuracy (compared to the radiance) to which the atmospheric effects can be measured as well as the accuracy of the RTC itself. One component of the first VC cross-calibration campaign was to compare RTC calculation accuracy. There are three ways to evaluate the results of such a comparison: use the same scene reflectance data and the same atmospheric parameter data as input to different RTCs; use the same target reflectance and the different atmospheric data as determined by each team as input to just one RTC; and, compare the results of each team using their data and their RTC extrapolation. Again, the results of this comparison are being evaluated.

3.0 Pre-launch test and development activities

Pre-launch activities are divided into two parts, theoretical and experimental. The theoretical validation uses previously collected data sets to develop, improve, and test the software needed for the VC. The experimental validation will be used in the pre-launch time frame to test data collection methods, evaluate test sites, and develop cooperative efforts with other MTPE sensor teams.

3.1 Field experiments and studies

Experimental validation: Pre-launch validation from an experimental point of view will serve three purposes: 1) validation-methodology tests; 2) test-site evaluation; 3) refinement and testing of the data reduction. Validation-methodology tests mean pre-launch field campaigns will be used to practice techniques needed in the post-launch era. Test-site evaluation will be used in the pre-launch time frame to help determine the uncertainties expected from each of the test sites to be used for the post-launch validation. Finally, the data from the pre-launch experiments will be used to test and refine the data reduction codes. The experimental approach for pre-launch validation is identical to the approach for the post-launch validation that is described in detail in section 4.1.

3.2 Operational Surface Networks

No plans for operational surface networks have been made. The primary reason for this is the lack of surface reflectance and radiance data. For example, the DOE ARM CART site is an excellent resource for information regarding the atmospheric composition which is needed for input to the RTC. However, use of these data is limited without information about the spectral reflectance and uniformity of the surface of the site at the same time the atmospheric data are collected. For sensor-to-sensor cross calibration it may be possible to infer the surface properties of a test site, however, the nonuniformities and spectral features will increase the uncertainty to such an extent that the cross calibration may be of little value.

3.3 Existing satellite/aircraft data

There exist a large number of data sets that can be used to evaluate the accuracy of the VC methods. However, there are no known data sets which include both VC and accurate OBC systems. Thus, there are no plans to use existing data sets.

4.0 Post-launch activities

After launch, validation will focus on determining the accuracy of the Level-1B data product as opposed to determining the accuracy of the VC approaches.

4.1 Planned field activities and studies

The plan described here relies on surface reflectance measurements of selected test sites, measurements of atmospheric properties over these sites, and radiance measurements made from aircraft at the time of sensor overpass.

Surface Reflectance Determination: The surface reflectance of a small area of the site is found by comparing radiometer measurements of the site to those from a diffusely reflecting panel of known reflectance. The reflectance panel is an aluminum sheet painted with barium sulfate. The panel is calibrated at RSG facilities using a pressed polytetrafluoroethylene standard by measuring the reflected radiance from the panel and standard at a variety of wavelengths and illumination angles. The calibration reference is a directional-to-hemispheric reflectance standard provided by the National Institute of Standards and Technology. Polynomial fits are made to the measured data to calculate the reflectance of the barium sulfate for the sun-view geometry and wavelengths for a given set of field measurements (Biggar et al., 1988).

Field measurements are made by transporting a spectroradiometer across the entire site. The radiometer samples at 1 nm intervals between 350 and 2500 nm. The instrument is extended away from the body of the vehicle and transported across the site. The spectroradiometer collects a number of samples along a straight-line path within some fraction of the area representing a 250 m x 250 m MODIS pixel. The calibration of the spectroradiometer is updated after each straight-line series of measurements. Reflectance of the site is determined in each spectral channel by comparing measurements of the site to those of the calibrated barium sulfate panel and averaging all of the measurements. Sun-angle changes and the bi-directional reflectance of the reflectance panel are taken into account when determining the reflectance. Global irradiance data are used to determine the significance of changes in diffuse skylight illumination.

Atmospheric measurements: The primary instrument used to characterize the atmosphere over the site is the solar radiometer. Two solar radiometers are used, one with ten bands and the other with three. For a solar radiometer the only calibration needed is a relative measurement of the maximum solar irradiance. The solar radiometers are relatively calibrated immediately prior to, during, or after each field campaign. Data from the ten-band radiometer are used in a Langley method retrieval scheme to determine spectral-atmospheric optical depths (Gellman et al., 1991). The optical depth results are used as part of an inversion scheme developed by the RSG to determine ozone optical depth and a Junge aerosol size distribution parameter (Biggar et al., 1990). The size distribution and columnar ozone are used to determine the optical depths at 1-nm intervals from 350 to 2500 nm.

The three-band radiometer is designed for columnar water vapor retrieval (Thome et al., 1994) using a modified Langley approach (Thome et al., 1992). Here, as for the optical depth retrieval, the primary uncertainty in water vapor is the instrument's relative calibration. The retrieved columnar water vapor is used as an input to MODTRAN3 to determine transmittance for the sun-to-surface-to-satellite path for 1-nm intervals from 350 to 2500 nm.

In the thermal infrared, the atmospheric measurements concentrate on obtaining profiles of temperature and humidity using radiosonde balloons.

Radiance measurements: There are two key factors in an accurate radiance measurement: calibration of the sensor and flying the sensor at a sufficient altitude to reduce atmospheric effects. Calibration of the sensors for both the solar reflective and thermal infrared will be done in the calibration facilities of the RSG.

Absolute spectral radiance in the VNIR/SWIR will be referenced to a NIST-calibrated spectral irradiance standard as well as checked against several NIST-traceable standard lamps. The absolute radiance of the sphere source is also traceable to NIST and to other EOS and non-EOS standard sources via the RSG's ultra-stable radiometers that have been developed for the VNIR and SWIR.

Another absolute radiance calibration method that will be used in the VNIR/SWIR is the SRBC. The accuracy of a SRBC is based on the irradiance-to-radiance BRF (bi-directional reflectance factor) of a diffusely reflecting panel and the absolute solar spectral irradiance. The BRF of the panel will be based on the same directional-hemispheric reflectance standard used in the calibration of the reflectance reference panels discussed above. Which set of spectral irradiance values should be used to quantitatively describe the sun in the SRBC method is still a matter for discussion.

Calibration of TIR radiance will be done using a variable-temperature blackbody simulator. As discussed in Section 2.2 the TIR calibration is NIST-traceable via absolute temperature calibrations. The deviations of the blackbody simulator from the ideal embodied in Planck's equation, for example, the difference from the ideal of unit emissivity, will be corrected. The uncertainties in the blackbody are the uncertainties in the corrections. The RSS of the uncertainty of the temperature standard plus the uncertainties in the corrections to Planckian behavior is then the uncertainty in the absolute accuracy of the blackbody simulator.

Once the sensors have been calibrated, they will be flown in an aircraft which allows the measurements to be made above much of the effects of the water vapor and the scattering by aerosols. The radiometers will be flown up to about 3 km above sea level. Based on previous work by the RSG, this altitude is high enough so that the uncertainty due to the atmospheric correction of the radiance at the satellite sensor in the solar reflective range is within +/- 0.1%. Work is still being done to evaluate the effect of the atmosphere in the TIR above 3 km.

Planned field campaigns: Figure 2 shows a proposed schedule for VC field campaigns during the A&E (activation and evaluation) phase of MODIS operation based on a June 1998 launch date. An intensive field campaign is recommended based on experience with previous satellite-borne sensors. Their calibration coefficients changed rapidly during the first few months of operation. A launch later in the year would require a different schedule because of variations in the weather and the surface conditions at the VC sites.   Both nadir (n or N, within +/- 5 degrees) and off-nadir (o or O, within +/- 30 degrees) MODIS over-flights are planned. The upper case letters indicate that both reflectance-based and radiance-based VCs will be performed. Lower case indicates reflectance -based only.

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Lake Tahoe						**O N O**	**O**		

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Nadir Views : N = reflectance and radiance based
n = only reflectance based

Off-nadir Views: O = reflectance and radiance based
o = only reflectance based

Figure 2. Proposed intensive field campaigns for A&E phase.

After the A&E phase two VCs per campaign are planned at approximately two month intervals. A second intensive campaign will take place about one year after the first, followed by single VC campaigns at three month intervals.

4.2 New EOS-targeted coordinated field campaigns

A recent field campaign to Lunar Lake, Nevada was made in late May, early June 1996. This campaign included VC teams from ASTER, MODIS, and MISR. The members from ASTER included both Japanese and US team members. This campaign was held to make comparisons between predicted TOA radiances made by each group as well as for practice for the EOS era when it is anticipated that additional coordinated field campaigns will be made.

A recommendation has been made that an international collaborative VC program be established for EOS sensors. This is to include non-EOS sensors where possible, for example, the French VEGETATION and the Japanese OCTS. The EOS Calibration Scientist is planning this international VC program in coordination with CEOS or by direct contact with other national space agencies. This program should thereby provide more frequent and appropriately spaced calibration up-dates, as well as the possibility of cross comparison of results from VC teams operating at different sites throughout the world (Slater and Biggar, 1996). The EOS Calibration Scientist is also planning to form an EOS Calibration Panel subgroup to coordinate and oversee all EOS-related VC activities.

This coordination will be of two kinds. The first is to perform joint campaigns similar to the one held at Lunar Lake. These coordinated campaigns are planned to be held with representatives of MISR, MODIS, ASTER, and Landsat-7 at a minimum. As before the principal reason for these campaigns will be to allow the TOA radiances from several VC teams to be compared. The second kind of coordination will be to use the results from other VC teams to increase the database of MODIS VC results to validate the cross calibration of these sensors. For instance, data collected as part of an independent MISR campaign could be used for the validation of MODIS TOA radiances.

As yet, there are no formal dates set for the joint VC campaigns. It is anticipated that a joint campaign will be held during or shortly after the A&E phase of the EOS AM-1 platform. The location of such a VC campaign is also to be determined. The basis for this decision is one of the purposes of the preflight work. One difficulty in selecting a suitable target for joint work is that it must be large enough to serve the needs of the large-footprint satellites and withstand multiple groups working at the site without each group interfering with the other’s work.

4.3 Needs for other satellite date

For the reflectance-based and radiance-based methods, there is no need for satellite data other than MODIS data. However, there will be a need to coordinate the collection of ASTER, MISR, and Landsat-7 data for any cross-calibration work that will be done. Except for ASTER this should not be a problem since MISR is currently a 100% duty-cycle sensor and Landsat-7 will not require scheduling for any of the selected sites.

4.4 Measurement needs at calibration/validation sites

The measurements needed for this validation are those described in section 4.1. Each method has a variety of needs depending upon the accuracy required. For instance, cross-calibrations between sensors can be done using only the data from each sensor. However, this would not be as accurate as the case in which ground- and aircraft-based spectral radiance and atmospheric data are also available.

4.5 Needs for instrument development (simulator)

Improvements in the accuracy of VC measurements could be achieved with the improvement of several types of instrumentation. For TIR radiance, VC measurements a more stable, airborne TIR radiometer needs to be developed. This radiometer should also be relatively easy to characterize and calibrate. For atmosphere characterization, better instrumentation for measuring the scattering phase function and aerosol index of refraction are needed. Also, for atmosphere characterization, a SWIR solar radiometer needs to be developed. Finally, for on-site surface characterization, an improved instrument to measure directional-hemispherical reflectance and one to measure two dimensional, simultaneous bi-directional reflectance factors need to be developed.

Regarding the measurement of the complex index of refraction of aerosols in the atmosphere: this parameter has been determined to be one of the least known, yet most important factors in the reflectance-based method.

The successful collection of data to validate the Level-1B data product would be improved through the increased availability, and decreased cost of an airborne system suitable for simulating MODIS data. This is because the 16-day orbit of MODIS decreases the chances of successful validation data sets at near-nadir look angles due to possible poor weather over the selected target site. An airborne simulator would allow data to be collected on any suitable day. These data could be used to evaluate the accuracy of the validation approach, thus increasing confidence in the data sets that are successfully collected for MODIS.

4.6 Geometric registration site

Geometric registration of the MODIS data will be needed. The geolocation of the VC site will be obtained from GPS data. Geometric registration will also be needed for cross-calibration approaches. The accuracy of this registration is dependent upon the test site. In general, knowledge of a pixel’s location on the ground must be known to better than 0.5 km. If the geometric registration is not known to better than this, we will have to rely on image matching techniques to register the data from one sensor to the data of another sensor.

4.7 Intercomparisons (multi-instrument)

This is a critical part of this validation plan because of the importance for determining biases in the radiances between sensors on the AM-1 platform and other MTPE sensors. It is expected that joint VC campaigns for ASTER, MISR, MODIS, and Landsat-7 will occur at least annually. The first step towards developing joint VC campaigns occurred with the May, June 1996 campaign discussed in Section 4.2.

5.0 Implementation of validation results in data production

5.1 Approach (including long-term calibration considerations)

The current role of the VC results will be to determine whether the calibration coefficients for MODIS need to be modified. Thus, if a VC campaign indicates that the calibration of the sensor has drifted more than the required accuracy, then in collaboration with a radiometric calibration advisory panel the MCST will modify the coefficients. The VC data will also be used to determine if the OBCs changed during launch. That is, a bias in the TOA radiance implies a change in the OBCs due to either shock, vibration, outgassing, water desorption, or zero-gravity load release.

5.2 Role of EOSDIS

The primary role of EOSDIS in this validation plan is to supply the Level-1B image data needed to determine the TOA radiance reported by the sensor for the test target.

5.3 Plans for archiving of validation data

Initial archiving of the validation data will be done at RSG facilities. The data will be archived in raw and processed format on Sun-based hard disks and 8-mm tapes using UNIX tar commands. Distribution of the data will be through ftp access. A word-wide web site is currently being developed for the RSG. This site will be used to allow others to see a list of available data, samples of the data, and summaries of the results. The site will also instruct users how to retrieve copies of the data from the ftp site.

Plans also call for VC and validation field measurement data to be archived at the Oak Ridge National Laboratory (ORNL). ORNL is the designated DAAC for field data and, in some cases, related aircraft data. As a first step in this direction, the field data collected during the first joint VC campaign in May/June 1996 are to be archived at ORNL. Recommendations regarding formatting and other details have been received by the RSG from Richard J. Olson of ORNL.

6.0 Summary

The validation plan described above uses both pre-launch and post-launch work. Pre-launch activities are divided into two parts. The first uses a theoretical approach to develop, improve, and test the software needed for the VC. The second uses an experimental approach to test data collection methods, evaluate test sites, and develop cooperative efforts with other MTPE sensor teams

After launch, validation of the at-sensor radiances will occur in a fashion similar to the experimental approach in the pre-launch phase. For the reflectance-based approach, the surface reflectance of a selected test site is measured concurrent with a MODIS overpass. At the same time, ground-based atmospheric data are collected. These data are used in a radiative transfer code to predict the at-sensor radiance. In the radiance-based approach, the same measurements are made, but in addition, radiances from the test site are made from an aircraft flying at 3 km above sea level. These radiances are corrected for the effects of the intervening atmosphere between the aircraft sensor and the satellite sensor to predict the TOA radiance.

Cross-calibrations with other EOS and non-EOS sensors, as well as measurements of the moon will also be used to determine the validity of the calibration coefficients used for MODIS.

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Appendix: Summary Charts

The Summary Charts were submitted separately and are therefore not included here.